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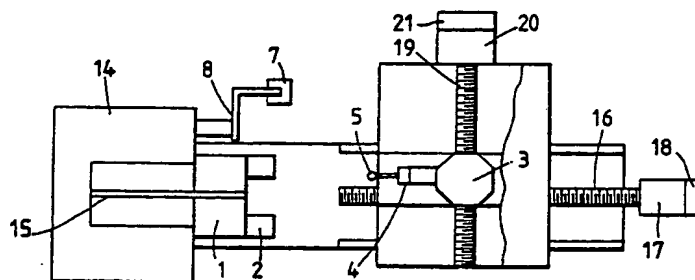
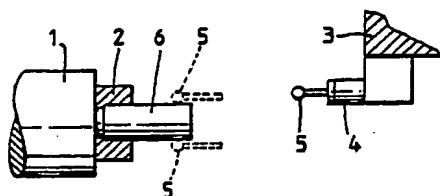
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(54) Title: A METHOD OF CALIBRATION FOR AN AUTOMATIC MACHINE TOOL



(57) Abstract

In an automatic lathe, a touch trigger probe (4) is calibrated (datumed) against an item (6) having a known reference dimension, instead of against the lathe chuck (2) or against a surface machined in a workpiece. The calibrated probe is then used to touch two diametrically opposed points of a feature (12) centred with respect to the axis of rotation of the chuck (2). From the mean of the co-ordinates of the two points touched, there is calculated an offset related to the difference between the assumed axis of rotation and the actual axis of rotation. This calibrates the machine to compensate for any drift between the actual axis of rotation and the machine's measurement origin.

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A METHOD OF CALIBRATION FOR AN AUTOMATIC MACHINE TOOL

The present invention relates to a method of calibration for an automatic machine tool, and more particularly for a lathe.

5 In the machine tool art, it is known to use a "touch trigger probe", of the kind described in US Patent No. 4,153,998, to trigger data processing means to produce an indication of x,y and z co-ordinates of a stylus of the probe in response to the stylus touching
10 a surface. Such probes are moved relative to the workpiece in a similar manner to the cutting tools themselves (e.g. on a tool-holding turret) and may be used both for checking the dimensions of a workpiece after machining by the machine tool and for controlling
15 the machine tool during its machining of the workpiece.

The measurement indications of x,y and z co-ordinates are taken with respect to a measurement origin of the machine tool. Prior to use, the probe may be
20 calibrated or "datumed" by causing it to trigger

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against one or more reference surfaces at fixed positions. This allows the calculation of "probe offsets" between the effective contact surfaces of the stylus and a nominal measurement position of the turret or other tool-holder in which the probe is mounted. These probe offsets are used to perform correction on subsequent measurements taken with the probe. Assuming the accuracy of the fixed reference position, such a correction takes account of the difference between the nominal measured position and the effective stylus contact surface.

We have found that a potential inaccuracy in probe datuming may occur in some machine tools if there is inaccuracy of positioning between the reference surface and the measurement origin. This may arise if there is deformation of the bed of the machine tool, causing a relative movement of the measurement origin. Such deformation may occur, for example, as a result of loading or thermal effects on the bed of the machine tool.

In the case of a machining centre, such problems do not normally arise, at least in the x and y axes, for the following reason. The cutting tool spindle of a machining centre is on the tool-holder, and hence its axis of rotation is local to the probe. The effects of machine bed deformation on the position of the measurement origin therefore have the same effect on both the measured position of the probe and on surfaces of the workpiece cut by the cutting tool. It follows that surfaces cut in the workpiece by the tool can be used as reference surfaces to calibrate the probe offset, since the effects of deformation then cancel each other out and do not give rise to a problem. Such techniques are described, for example, in US Patent

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No. 4,281,385 and British Patent Application
No. GB 2,108,715 A.

In the case of lathes, it is known to calibrate the
5 probe offset in the manner described above, using
reference surfaces provided on the workpiece-holding
chuck. See for example US Patent No. 4,382,215, and
"Users Handbook - Programs for Probes, Component
Inspection and Tool Datuming with Fanuc 6TB Control",
10 Part 3, pages 25-35, published in 1984 by Renishaw
Electrical Limited. However, we have found that this
gives rise to the above-noted problem due to machine
deformation. The problem cannot be removed simply by
datuming the probe against surfaces machined in a
15 workpiece by the use of the lathe, because the axis of
rotation of the chuck is remote from the tool holder
which holds the probe. Such datuming processes, we now
realise, involve an assumption that the position of the
axis of rotation of the chuck or workpiece can be
20 accurately known relative to the measurement origin.
In practice, this is not accurately known so if the
machine is subject to deformation, and the inaccuracy
is not cancelled out in the manner that it would be
with a machining centre, because the axis of rotation
25 is not local to the probe.

According to the present invention, there is provided a
method of calibration for an automatic machine tool
having workpiece-holding means which is rotatable for
30 machining a workpiece held therein, data processing
means, and a trigger probe, which probe can be
triggered against a point on the surface of the
workpiece, in response to which the data processing
means produces information representative of positional
35 co-ordinates of the probe at the trigger point, the
co-ordinates being with respect to a datum point which

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is based upon an assumed axis of rotation of the workpiece, the method comprising:

5 (a) calibrating the probe, by triggering it against at least one point on an item having a known dimension and, using said dimension and a positional co-ordinate of the or each trigger point as indicated by the data processing means, computing a probe correction offset; and

10 (b) calibrating the machine tool, by providing a feature centred with respect to the actual axis of rotation; triggering said probe against first and second diametrically opposite points on said feature with respect to the axis of rotation; and, on the basis of the mean of respective positional co-ordinates of
15 the trigger points as indicated by the data processing means, corrected by the probe correction offset, computing an offset related to the difference, if any, between the actual axis of rotation and the assumed axis of rotation..

20

The feature centred with respect to the actual axis of rotation is preferably provided by machining the feature into a workpiece, since this ensures concentricity and obviates inaccuracies which can be
25 caused by datuming on a surface of the chuck (which may become distorted owing to clamping loads).

The present invention will now be described, by way of example, with reference to the accompanying drawings,
30 in which:

Figs. 1-4 are schematic diagrams for use in explaining the principle of one aspect of an example of the invention;

35 Figs. 5, 6 and 7 are schematic diagrams for use in explaining how measurements are made after a calibration for a stylus dimension has been

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accomplished;

Figs. 8,9,10b and 11 are schematic diagrams for use in explaining the principle of a second aspect of the example of the invention;

5 Figs. 14a,14b and 15 are schematic diagrams for use in explaining an extension of the second aspect of the example of the invention.

The following example of the invention first describes a method for calibrating a touch trigger probe used with an automatic lathe, by deriving the effective (electronic) diameter of the spherical stylus of the probe. It then describes a method of using the thus-calibrated probe to calibrate for the actual
15 centre-line (axis of rotation) of the lathe.

Referring first to Fig. 1, reference numeral 1 denotes the chuck of an automatic lathe having chuck jaws 2. Reference numeral 3 denotes a tool turret of the lathe,
20 carrying a touch trigger probe 4 having a spherical stylus 5. Reference numeral 6 denotes an item for example a reference bar or cylinder, held in the jaws 2 as concentrically as possible and of known diameter Dref. The stylus 5 of the probe 4 is caused to touch
25 the item 6 at two diametrically opposite points as shown by broken lines Fig. 1. Referring to Fig. 2, if X1 and X2 are the x-co-ordinates as measured by data processing means coupled with the probe for the two points of contact, then the effective (electronic)
30 diameter Db of the stylus (which is smaller than the actual, physical diameter of the stylus), is given by:

$$Db = Dref - (X1 - X2)$$

The data processing means is programmed to effect a
35 calculation on the basis of the above equation to produce an indication of the effective (electronic)

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diameter of the stylus 5 for use in correcting co-ordinate measurements on the basis of Db .

If the co-ordinate measuring system comprising the data processing means and the probe has been calibrated with respect to the centre-line (axis of rotation) of the lathe, then a single touch method at a point whose x-co-ordinate is measured to be $X1$ can be used to obtain the effective stylus radius (Rb) by the equation:

$Rb = Rref - X1$, where $Rref$ is the known radius of the item 6.

The computation of the effective stylus diameter (or radius) could be carried out with respect to an internal bore in an item 6 held in the chuck jaws 2, the bore being of known diameter $Dref$ - see Fig. 3. Again:

$Db = Dref - (X1 - X2)$ or

$Rb = Rref - X1$ if the system has been calibrated with respect to the centre-line of the lathe.

As an alternative (due to machine constraints) to calibration for stylus diameter (or radius) with respect to an item 6 held in the jaws 2, an item for calibration purposes may be used which is held by a remotely mounted calibration arm - see Fig. 4. In Fig. 4, reference numeral 7 denotes an item of known dimensions carried by a fixed or automatically re-positionable arm 8. For greatest accuracy, preferably the arm 8 can be swung so that the item 7 is in the vicinity of the centre line of the lathe during the calibration. It is swung out of the way afterwards. Item 7 could, as shown, be a cube of known thickness D , the effective diameter Db of the stylus 5 being given by:

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$$D_b = D - (X_1 - X_2)$$

After the system has been calibrated for the effective diameter or radius of the stylus 5, then the value of the latter may be taken into account when using the probe 4 to measure dimensions. Referring to Fig. 5, if the internal diameter D1 of a bore in a workpiece 9 is to be measured by touching the stylus 5 at two diametrically opposite points of the bore, then D1 is found by adding the diameter Db of the stylus 5 to the diameter of the bore as actually measured by the system comprising the probe 4 and the data processing means. Referring to Fig. 6, if the external diameter D2 of a workpiece 10 is to be measured by touching the stylus 5 at two diametrically opposite points, then the diameter D2 is found by subtracting the diameter Db from the diameter as actually measured by the system comprising the data processing means and the probe 4. Where diameter measurement is not possible directly by virtue of machine constraints, a single touch method may be used provided that the probe centre-line with respect to the lathe centre-line has recently been upgraded. For example, referring to Fig. 7, the radius R3 of a workpiece 11 is found from the difference between the radius as actually measured by the system comprising the data processing means and the probe 4 and the effective radius of the stylus 5; and the radius R4 of the workpiece 11 is found by adding the radius as actually measured by the system comprising the data processing means and the probe 4 and the effective radius of the stylus 5.

Incidentally, if the item with respect to which the above computation to determine the effective diameter (or radius) of the stylus 5 does not have its axis parallel with the centre-line (axis of rotation) of the

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machine tool, then this needs to be compensated for in computation of the effective diameter by ascertaining the angle between the two axes and applying the cosine principle to $(X1 - X2)$ or $X1$.

5

There will now be described a method of calibrating for the actual centre-line of the lathe. This might differ from the assumed centre-line on the basis of which the system comprising the data processing means and the
10 probe 4 provides co-ordinate information, for example due to thermal or other effects. (In practice, the co-ordinates are taken from an arbitrary measurement origin of the system, which is normally assumed to be fixed with respect to the centre-line; an assumption
15 which might be invalid at any given time because of the thermal or other effects. Calibration as described below compensates for this).

First, referring to Fig. 8, a workpiece 12 is turned on
20 the lathe using a tool to a diameter suitable for the stylus 5 on the probe 4 to contact diametrically opposite points, as shown by the broken lines in Fig. 8.

25 Referring to Fig. 9, if:

$X1$ is the x-co-ordinate of one point of contact as measured by probe 4 and the data processing means;

$X2$ is the x-co-ordinate of the other point of contact as measured by the probe 4 and the data

30 processing means; and

Xc is the assumed x-co-ordinate of the centre-line of the lathe,

then the error Xe in the system's assumption of the x-co-ordinate of the centre-line of the lathe is given

35 by:

$$Xe = Xc - Xm \text{ where}$$

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$X_m = (X_1 + X_2)/2$, namely the mean of X_1 and X_2 .

Incidentally, the probe can be arranged so that its principal axis is parallel or normal to the rotational axis (centre-line) of the lathe - see Figs. 10a and 10b. This applies also to the earlier described method of calibration for stylus diameter or radius.

Once the error X_e in the assumed centre-line has been computed, this can be used by the data processing means to directly modify the offset with respect to a datum point with respect to which position is defined, or by using the error value to correct co-ordinate values derived using a probe. In Fig. 11, reference numeral 13 denotes the datum point and 0 is the x-axis offset to the probe centre-line.

Figs. 12 and 13 are schematic side and plan views of an automatic lathe with which the present invention may be used. Reference numeral 14 denotes a headstock of the lathe; reference numeral 15 denotes the lathe spindle; reference numeral 16 denotes an z-axis lead screw; reference numeral 17 denotes an z-axis drive; reference numeral 18 denotes an z-axis encoder; reference numeral 19 denotes an x-axis lead screw; reference numeral 20 denotes an x-axis drive; reference numeral 21 denotes an x-axis encoder; and reference numeral 22 denotes a cabinet within which is a computerised numerical control unit data processing means. As well as controlling the operation of the lathe, the data processing means is also programmed to store co-ordinate positional information and perform calculations on the basis of the above for determining the effective diameter or radius of the stylus 5 and the error, if any, between the assumed centre-line of the lathe and the actual centre-line.

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Incidentally, the item 7 could also itself operate as a touch trigger probe, needing a greater contact force to cause a triggering reaction than the probe 4, and be used, for example, in setting up tools carried by the
5 lathe.

There will now be described an extension of the present invention whereby calibration is repetitively carried out during operation of the lathe to calibrate for a
10 shift in the actual centre-line of the lathe.

Referring to Fig. 14a, this shows the condition of a workpiece 23 with the actual centre-line in its correct, assumed position, Fig. 14b showing the position of workpiece 23 in a second condition in which the actual
15 centre-line has shifted. In the first condition, the probe 4 will be referred to the correct centre-line (axis of rotation) from its datum point and a tool offset, or a separate data store can be modified to store the probe offset from the datum point to the
20 centre-line of the probe 4. In the second condition, the lathe spindle has moved for an unspecified reason by an unknown amount. The specification of the datum position with respect to the actual centre-line of the lathe is no longer valid. A re-calibration for the
25 actual centre-line of the lathe then needs to be carried out on the basis of the foregoing. Such re-calibration may be carried out repetitively during a prolonged sequence of operations to continuously re-calibrate for a shift in the actual centre-line of
30 the lathe. It will be noted that only the second half of the procedure described above (calibration for the centre line) needs to be repeated; the probe itself will not normally need recalibration since it has been calibrated against the known dimension of the reference
35 item 6 or 7. It is also to be noted that a subsequent

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calibration of the lathe will be for a specific position thereon and, if the shift of the centre-line results in an angular error between the assumed centre-line and the actual centre-line, then

- 5 re-calibration may be repeated for different zones - see Fig. 15 in which, on the basis of a knowledge of the angular error and the distance offset in the z direction at the position of the probe 4 at re-calibration, the errors at zones 24a, 24b, 24c, 24d ...
- 10 may be calculated by the data processing means. The errors due to the angular inclination may be made available for incorporation into an interactive control system where the software of the data processing means adjusts readings of positional measurement.
- 15 Alternatively, the data may be fed out to an external computer capable of re-adjusting a lathe control system without the need for compensations or modifications of positional data.
- 20 Incidentally, as an alternative to using a particular item 12, any convenient diameter on an actual workpiece being operated on may be used for calibration for a shift in lathe centre-line, as the process is size independent; or one may provide a nominal diameter
- 25 which may be destroyed later either on the workpiece itself or on a fixture on the lathe.

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CLAIMS:

1. A method of calibration for an automatic machine tool having workpiece-holding means which is rotatable for machining a workpiece held therein, data processing means, and a trigger probe, which probe can be
5 triggered against a point on the surface of the workpiece, in response to which the data processing means produces information representative of positional co-ordinates of the probe at the trigger point, the co-ordinates being with respect to a datum point which
10 is based upon an assumed axis of rotation of the workpiece, the method comprising:
- (a) calibrating the probe, by triggering it against at least one point on an item having a known dimension and, using said dimension and a positional co-ordinate
15 of the or each trigger point as indicated by the data processing means, computing a probe correction offset; and
- (b) calibrating the machine tool, by providing a feature centred with respect to the actual axis of
20 rotation; triggering said probe against first and second diametrically opposite points on said feature with respect to the axis of rotation; and, on the basis of the mean of respective positional co-ordinates of the trigger points as indicated by the data processing
25 means, corrected by the probe correction offset, computing an offset related to the difference, if any, between the actual axis of rotation and the assumed axis of rotation.
- 30 2. A method according to Claim 1, wherein the probe is calibrated by triggering it against two opposite points of the item having a known dimension, and calculating the probe correction offset Db as:

$$Db = Dref - (X1 - X2)$$

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where Dref is said known dimension, and X1 and X2 are the co-ordinates of the trigger points as measured by the data processing means.

- 5 3. A method according to Claim 1 or Claim 2, wherein the feature centred with respect to the actual axis of rotation is provided by machining the feature into a workpiece.
- 10 4. A method according to any one of the preceding claims, wherein said offset Xe related to the difference between the actual axis of rotation and the assumed axis of rotation is given by
- $$Xe = Xc - Xm$$
- 15 where Xc is the assumed positional co-ordinate of the axis of rotation, and Xm is said mean of the positional co-ordinates of the trigger points of said feature centred on the actual axis of rotation.
- 20 5. A method according to any one of the preceding claims, in which step (b) is repeated at subsequent times to re-calibrate the machine tool.
- 25 6. A method according to any one of the preceding claims, wherein step (b) is repeated for different working zones of the machine tool.

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Fig.1.

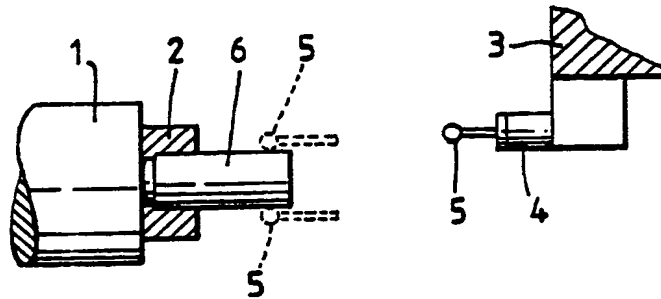


Fig.2.

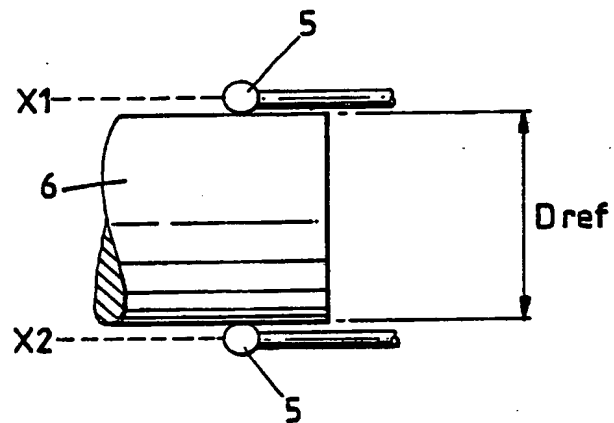
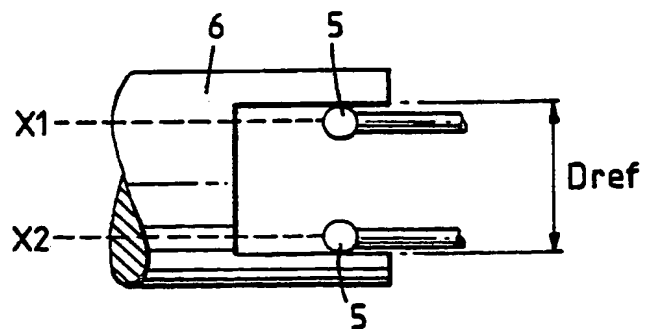
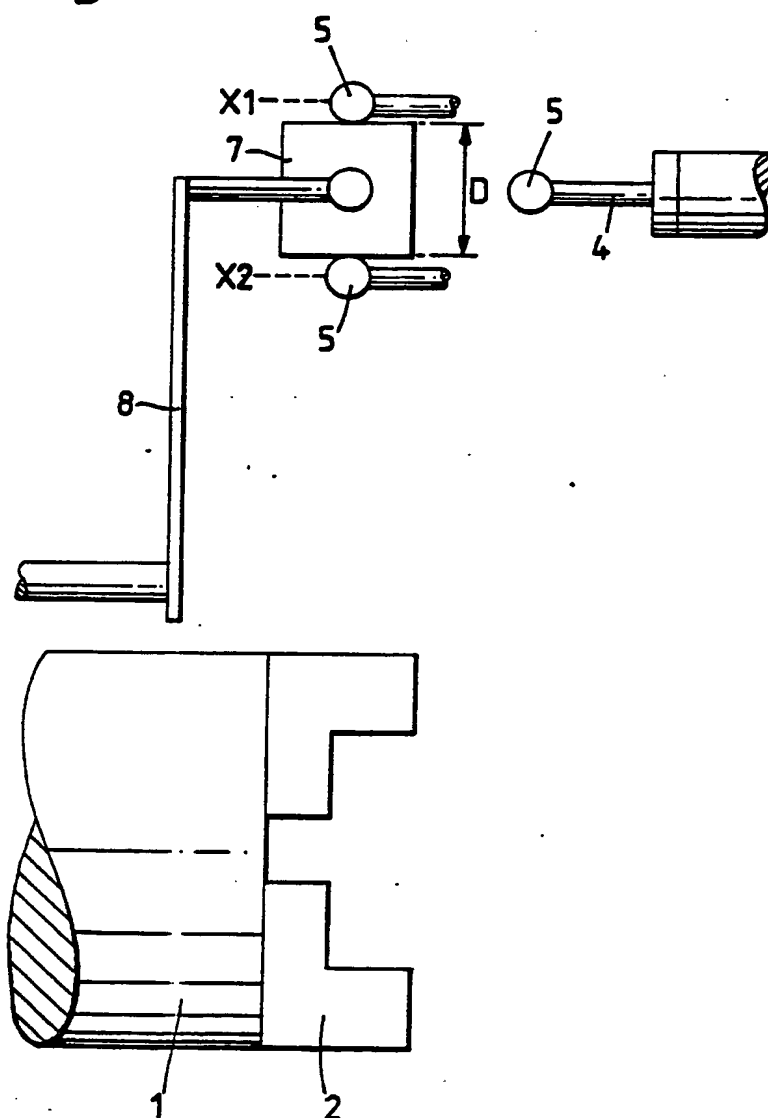


Fig.3.



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Fig.4.



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Fig. 5.

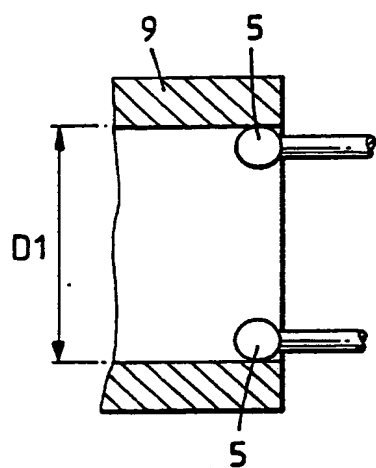


Fig. 6.

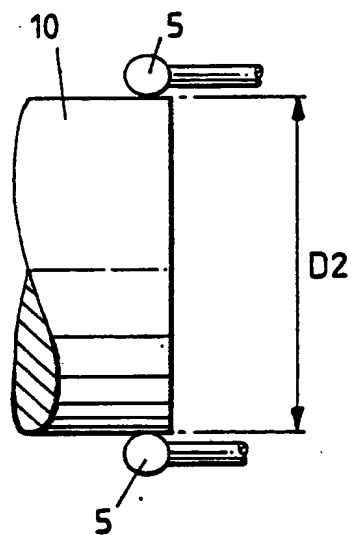
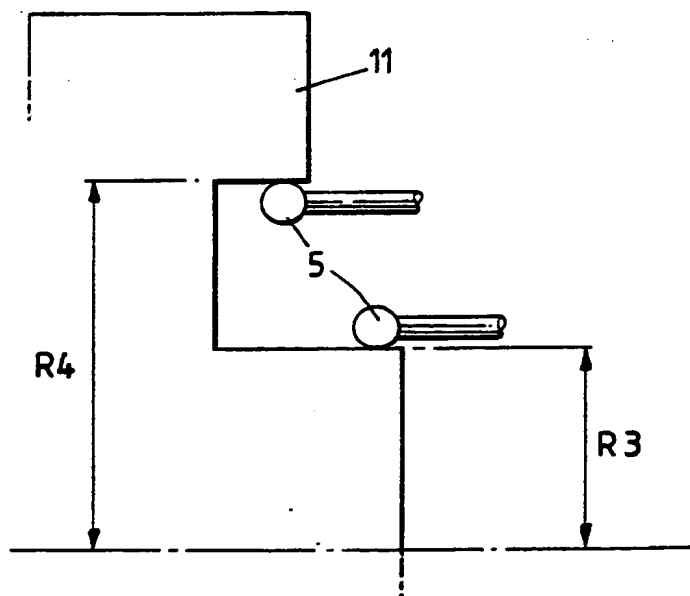


Fig. 7.



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Fig.8.

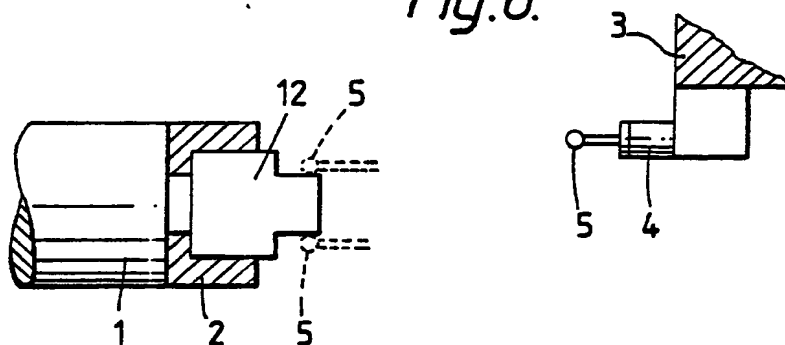


Fig.9.

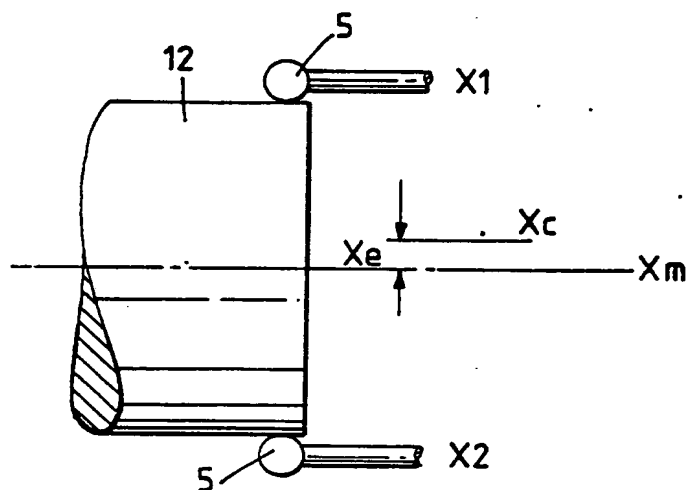


Fig.10 a.

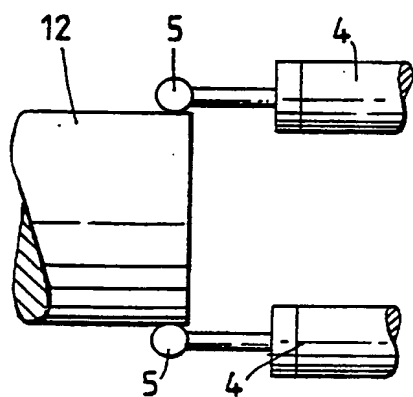
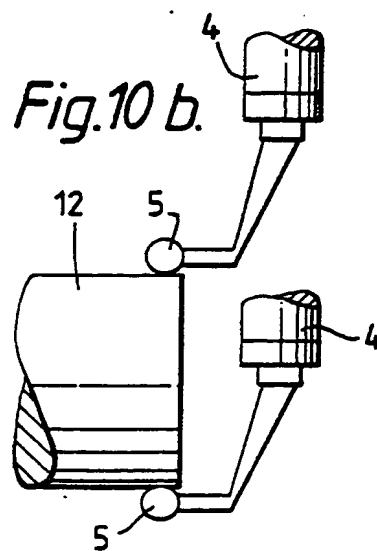


Fig.10 b.



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Fig.11.

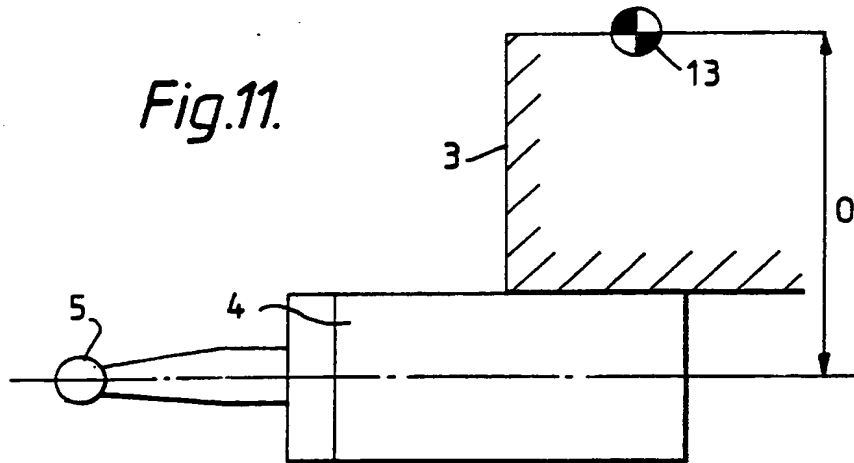


Fig 12

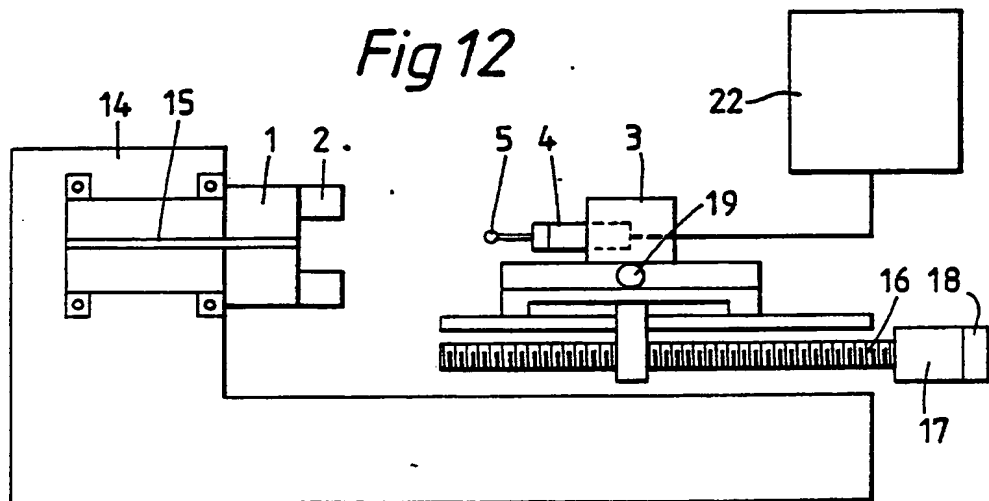
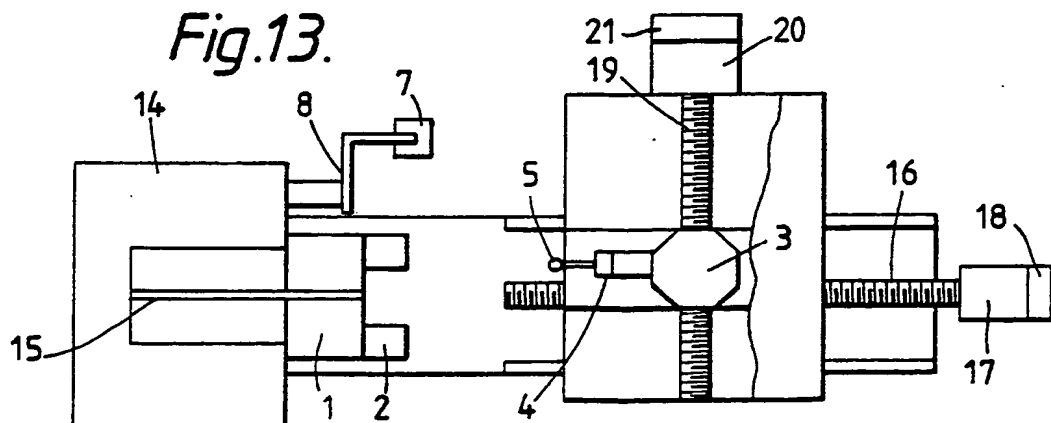


Fig.13.



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Fig.14a.

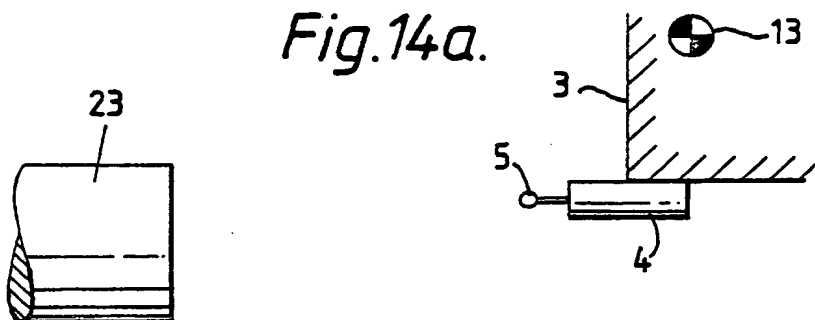


Fig.14b.

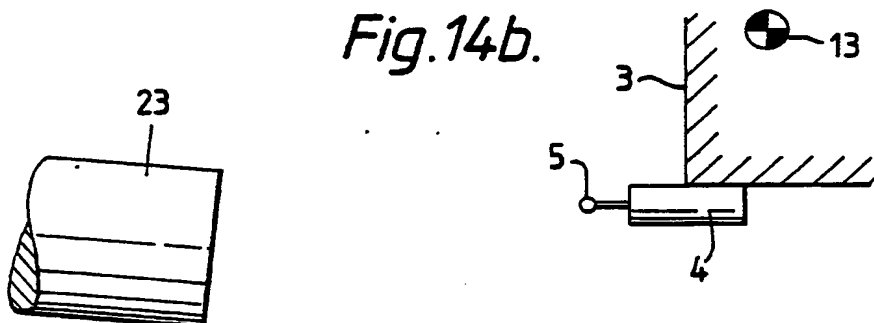
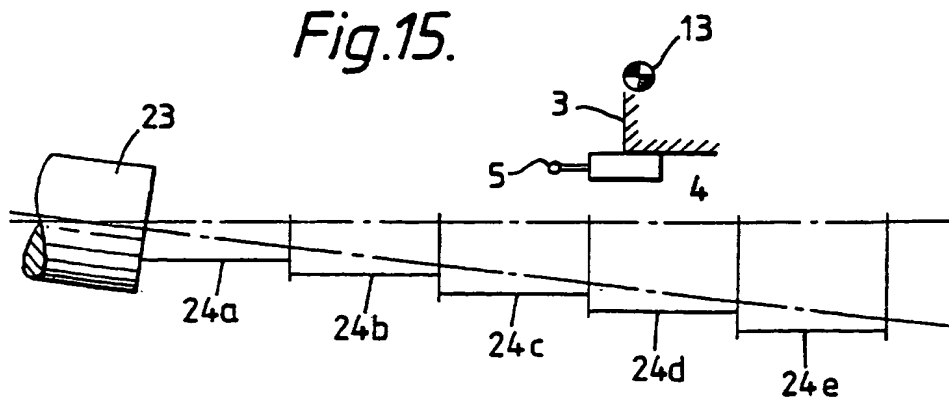


Fig.15.

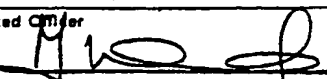


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INTERNATIONAL SEARCH REPORT

PCT/GB 87/00644

International Application No.

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ⁶		
According to International Patent Classification (IPC) or to both National Classification and IPC		
IPC ⁴ : G 05 B 19/18		
II. FIELDS SEARCHED		
Minimum Documentation Searched ⁷		
Classification System	Classification Symbols	
IPC ⁴	G 05 B	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched ⁸		
III. DOCUMENTS CONSIDERED TO BE RELEVANT⁹		
Category ¹⁰	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
X	US, A, 4554495 (DAVIS) 19 November 1985 see the whole document --	1-6
Y	US, A, 4562392 (DAVIS et al.) 31 December 1985 see the whole document --	1-6
Y	GB, A, 2069142 (McMURTRY) 19 August 1981 see the whole document --	1-6
Y	GB, A, 2033610 (ALFRED HERBERT LTD) 21 May 1980 see the whole document -----	1-6
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IV. CERTIFICATION		
Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	
18th November 1987	11 DEC 1987	
International Searching Authority	Signature of Authorized Officer	
EUROPEAN PATENT OFFICE	M. VAN MOL 	

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON

INTERNATIONAL APPLICATION NO.

PCT/GB 87/00644 (SA 18637)

This Annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 26/11/87

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 4554495	19/11/85	GB-A- 2163872	05/03/86
		FR-A- 2569597	07/03/86
		DE-A- 3530567	13/03/86
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For more details about this annex :

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